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**Urbanization drivers differentially affect ground arthropod assemblages in the city of Turin (NW-Italy)**

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(Article begins on next page)

# Urban Ecosystems

## Urbanization drivers differentially affect ground arthropod assemblages in the city of Turin (NW-Italy) --Manuscript Draft--

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<b>Abstract:</b>	<p>Urbanization is a complex process associated with environmental changes affecting many biotic and abiotic ecosystem components, which cause the alteration of biological communities, habitat features, connectivity and stability. In particular, the urbanization process is usually associated with a decrease in species richness that parallels a general increase in the overall abundance of individuals, mostly due to generalist and tolerant species taking advantage of the altered environmental conditions and outcompeting and excluding native species. We here adopted a hierarchically nested sampling design to investigate the response of ground arthropods to the combined effects of multiple facets of urbanization, namely increased impervious surface cover, temperature and patch isolation, measured at small, intermediate and large spatial scale. We studied 15 plots of 150 m in diameter located in the city of Turin (NW-Italy), along an urbanization-cover gradient ranging from suburbia to the city center. For each plot we considered the level of urbanization at three different scales (circular buffers with a 100, 400 and 1600 m radius). Within each plot, we identified a control and an isolated subplot, and in each subplot, we measured ground temperature using dataloggers and we sampled ground arthropods with pitfall traps. Firstly, by relating ground temperature and urbanization cover, we showed that temperature values reflected an Urban Heat Island (UHI) effect, which indicates increasing values of temperature along the urbanization gradient. This trend was particularly evident at large scale regarding daily and diurnal temperature, and at small scale regarding nocturnal temperature. Secondly, we demonstrated that different groups of ground arthropods respond differently to urbanization cover, with major effects at the largest spatial scale. Finally, we extrapolated the differential contribution of urbanization cover, UHI-effect and patch isolation to the observed activity density of the investigated taxonomic groups: Coleoptera and Hemiptera were influenced by temperature, whereas Hymenoptera, Collembola, Acari and Araneae were mainly influenced by</p>	

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# Urbanization drivers differentially affect ground arthropod assemblages in the city of Turin (NW-Italy)

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## ABSTRACT

Urbanization is a complex process associated with environmental changes affecting many biotic and abiotic ecosystem components, which cause the alteration of biological communities, habitat features, connectivity and stability. In particular, the urbanization process is usually associated with a decrease in species richness that parallels a general increase in the overall abundance of individuals, mostly due to generalist and tolerant species taking advantage of the altered environmental conditions and outcompeting and excluding native species. We here adopted a hierarchically nested sampling design to investigate the response of ground arthropods to the combined effects of multiple facets of urbanization, namely increased impervious surface cover, temperature and patch isolation, measured at small, intermediate and large spatial scale. We studied 15 plots of 150 m in diameter located in the city of Turin (NW-Italy), along an urbanization-cover gradient ranging from suburbia to the city center. For each plot we considered the level of urbanization at three different scales (circular buffers with a 100, 400 and 1600 m radius). Within each plot, we identified a control and an isolated subplot, and in each subplot, we measured ground temperature using dataloggers and we sampled ground arthropods with pitfall traps. Firstly, by relating ground temperature and urbanization cover, we showed that temperature values reflected an Urban Heat Island (UHI) effect, which indicates increasing values of temperature along the urbanization gradient. This trend was particularly evident at large scale regarding daily and diurnal temperature, and at small scale regarding nocturnal temperature. Secondly, we demonstrated that different groups of ground arthropods respond differently to urbanization cover, with major effects at the largest spatial scale. Finally, we extrapolated the differential contribution of urbanization cover, UHI-effect and patch isolation to the observed activity density of the investigated taxonomic groups:

Coleoptera and Hemiptera were influenced by temperature, whereas Hymenoptera, Collembola, Acari and Araneae were mainly influenced by urbanization, especially in control subplots. Our results emphasize how a multitaxonomic approach can help unravel patterns of community assembly in urban areas.

**Keywords:** UHI-effect, fragmentation, activity density, multitaxonomic approach

## INTRODUCTION

Land-use change has been recognized as one of the major drivers affecting biodiversity (Sala et al. 2000) and, over the recent decades, the conversion of natural lands into urban areas has been greatly increasing worldwide (Seto et al. 2011). From an ecological standpoint, urban ecosystems are associated with substantial changes in the physical environment, among which the increasing nutrient and pollution levels are the most evident (Parris 2016). However, other physical alterations may affect urban areas too. For instance, due to the amount of area characterized by a high built-up cover, ambient temperature in city cores is typically 1.5-2°C higher than in the rural surroundings, i.e. the Urban Heat Island (UHI) effect (Oke 1982; Arnfield 2003). Higher urban temperatures mainly stem from an anthropogenic release of heat, combined with the heat stored and re-radiated by massive and complex urban structures (Rizwan et al. 2008). Urbanization effects are apparent also at a landscape scale, as the continuous growth of built-up areas interrupts the semi-natural habitats surrounding cities, creating partially or completely small isolated patches (Parris and Schneider 2009; Rotholz and Mandelik 2013). In addition, the residual natural habitat is often converted into highly impermanent and disturbed habitats, mainly derelict sites — such as brownfields, landfills, gravel and sand pits, industrial dumps and railway lands — characterized by altered soil physical and chemical properties (Small et al. 2003; Tóthmérész et al. 2011).

Such biophysical processes linked to urbanization can have wide-ranging effects on populations and species by altering the quantity, quality, temporal and spatial arrangement of resources (Parris 2016). For instance, the Urban Heat Island (UHI) effect may alter the composition of biological communities due to differences in the thermal tolerance of species, causing a shift in community composition towards species with preferences for higher temperatures (Merckx and Van Dyck, 2019). In addition, as suitable habitat patches in urban environments are often isolated, they are more likely to be colonized by good rather than poor

dispersers (see Piano et al. 2017a for an example on ground beetles and Merckx and Van Dyck 2019 for lepidopterans). As a consequence, the number of species is expected to decrease in residual habitat patches (McKinney 2008).

Nonetheless, urban fragments can be characterized by abundant populations of some taxa, since synanthropic urban species may outcompete and exclude native species (Shochat et al. 2010; Mammola et al. 2018), leading to contradictory results (e.g. Christie et al. 2010; Faeth et al. 2011; Fortel et al. 2014; Saari et al. 2016; Banaszak-Cibicka et al. 2018; Alvarez Guevara and Ball 2018). In fact, not only do organisms react differently to environmental changes in urban areas, but they also differ in their response to the scales at which urbanization takes place, as a result of their combination of traits, e.g. dispersal capacity or foraging range (see Egerer et al. 2017, Merckx and Van Dyck 2019, Merckx et al., 2018b). These changes in biodiversity may, in turn, affect key ecosystem processes, like nutrient cycling, decomposition and pest control (McIntyre et al., 2001). Thus, the understanding of the ecological implications of the urbanization process is gaining more and more importance in the scientific debate.

Since ground arthropods cover all of the consumers' trophic roles — i.e. herbivores, predators and decomposers — they are abundant, diverse and responsible for numerous ecosystem functions. They exhibit a variety of dispersal capacities and foraging ranges, likely being affected by urbanization at different spatial scales (Egerer et al. 2017, Eggenberger et al. 2019). Many studies have shown how local factors and habitat types in urban patches may negatively affect the abundance of different arthropod groups (Christie et al. 2010; Norton et al. 2014; Philpott et al. 2014; Otoshi et al. 2015; Laguki et al. 2017; Kyrö et al. 2018), but little is known about their scale of response (see Egerer et al. 2017, Merckx et al. 2018a and Merckx and Van Dyck 2019 for some evidences). In addition, the Urban Heat Island (UHI) effect and patch isolation have been shown to seriously affect single species dynamics (Meineke et al. 2013; Youngsteadt et al. 2015; Kaiser et al. 2016) and community composition in urban environments (Clavero et al. 2011; Menke et al. 2011; Piano et al. 2017a; Meineke et al. 2017; Merckx et al. 2018a; Merckx et al. 2018b). However, to date, the extent to which the combined effect of these phenomena affects ground arthropod abundance has never been addressed by simultaneously examining multiple taxonomic groups. Given their pivotal role in ecosystem functionality — e.g. litter decomposition and pest control —, understanding how urbanization impacts

multiple groups of ground arthropods is necessary to predict alterations in the provision of ecosystem services, which has proved to be strictly dependent on biodiversity in urban areas (Zitter 2016).

Here we performed a field study to investigate the combined effect of increasing urbanization cover (i.e. increasing impervious surfaces, Elvidge et al. 2007), urban heat-island effect and isolation within an urban area on six orders of ground arthropods, differing in their dispersal capacity and foraging behaviour. We selected 15 sampling sites along an urbanization gradient in the city of Turin (Italy), and in each site we sampled arthropods in an isolated green patch (traffic roundabouts) and in the closer wider green area. In addition, within each sampling patch, we measured temperature values during the entire sampling period. We aimed at: i) checking the presence of the UHI-effect in the study area and the scale of temperature response to urbanization, and whether it is influenced by patch isolation; ii) examining at which scale urbanization mostly affects ground arthropod assemblages, by considering the percentage of impervious surfaces at different scales; and iii) evaluating the differential effect of urbanization, UHI-effect and isolation on the activity density of different groups of ground arthropods and whether these groups show different responses to these parameters. We hypothesized that: i) temperature would increase along the urbanization gradient as a consequence of the UHI-effect; ii) the scale of response would differ depending on the examined arthropod group; and iii) arthropod groups would be differentially affected by urbanization, temperature and isolation, showing distinctive responses.

## MATERIALS AND METHODS

### Sampling design

This study was conducted in the metropolitan area of Turin (NW-Italy, approximately 900,000 inhabitants), within 15 km of the city center. The city of Turin was founded by the Romans around the year 50 B.C. and it is located between the Western Alps and the beginning of the Po plain in the region of Piedmont. The altitude ranges between 220 and 280 m a.s.l. and the climate is continental.

In order to test the effect of patch isolation independently from urbanization level, we adopted a specific sampling design consisting of a random selection of a total of 15 sites (plots) with open vegetation along an

urbanization gradient: from less urbanized areas in the suburbia to the city center (Fig. 1). In order to examine how patch isolation affects the community of ground arthropods, in each plot we identified two sampling subplots: i) an isolated subplot, located in a roundabout with open vegetation, maintained by regular mowing, and ii) a control subplot, located in the nearest green area with the same type of vegetation, being represented by small green urban patches (1,000 m<sup>2</sup>), urban parks or semi-natural areas at the city borders (up to a few hundreds of hectares). The whole sampling plot –including the two subplots – was a circular area with a diameter of 150 m (approximately 18,000 m<sup>2</sup>). We chose roundabouts as appropriate proxies for isolated patches because they are completely surrounded by roads, which constitute a partial - or even a complete - barrier for many organisms (Jaeger and Fahrig 2004). Both control and isolated subplots were, and still are, managed by the public green authority of Turin, which mowed the grass once during the study period in all subplots, thus guaranteeing the same degree of disturbance in both subplot categories. Roundabouts ranged from 6 to 30 m radius (i.e. approximately from 150 to 2,500 m<sup>2</sup> in surface area), and were equally distributed among three age classes (1 = less than 10 years of age ; 2 = 10 years of age; 3 = more than 10 years of age), which were estimated from historical aerial maps using Google Earth (<https://www.google.com/earth/download/ge>) (Tab. 1). The average distance between sampling plots was of 8,878 m ( $\pm 1,705.6$ ), ranging from 1,408 to 18,512 m.

In order to investigate the scale of response of ground arthropod groups to urbanization cover, we calculated the degree of urbanization for each plot in three progressive larger buffers, defined as circles with a 100 m (small scale), 400 m (medium scale) and 1,600 m (large scale) radius - with the roundabout as the center. By using digital maps updated to 2017 ([http://geomap.reteunitaria.piemonte.it/WEBCAT/CAPABILITIES/wms\\_regp\\_basecarto10bn\\_2017.xml](http://geomap.reteunitaria.piemonte.it/WEBCAT/CAPABILITIES/wms_regp_basecarto10bn_2017.xml)) in QGis (Quantum Gis Development 2018) with a resolution of 5 m, we delimited impervious surfaces, namely buildings, roads and parking areas, within each buffer. We then calculated the urbanization cover as the ratio between the area covered by impervious surfaces within the buffer and the total area of the buffer. To explore the UHI effect, we monitored temperature at a ground level in both the isolated and the control subplot of each sampling plot, using 30 HOBO® Pendant® Temperature Data Loggers (Onset Computer Corporation), which were set to record temperature every hour. Data loggers were installed and shielded with an ad-hoc, custom fabricated shield consisting of a shade cloth at the beginning of the experiment, and were



downloaded **after** each sampling occasion. For each subplot we calculated the average daily (0 a.m. – 12 p.m.), diurnal (7 a.m. – 6 p.m.) and nocturnal (7 p.m. – 6 a.m.) temperatures **for** every sampling session.

## Data collection

Within each subplot, ground-active arthropods were captured using a triplet of pitfall traps (5-10 m apart), placed at least 20 cm from the subplot border (i.e. the road) and at least 5 m apart to increase catching efficiency (Ward et al. 2001). Pitfall traps consisted of plastic jars (diameter 90 mm, length 110 mm) dug into the ground, ensuring the upper edge of the glass **was flush** with the soil surface. Pitfall traps were filled with 20 ml of 50% propylene glycol, which is a neutral field sampling preservative, with no attractive or repulsive characteristics for most arthropod groups. The pitfall traps were placed on the same day (May 16th, 2017) and were emptied every three weeks for a total of three sampling sessions (June 6<sup>th</sup>, June 27<sup>th</sup> **and** July 18<sup>th</sup> 2017).

Collected material was placed into vials containing **70%** ethanol to preserve specimens. The specimens were sorted, identified following Angelini et al. (2002) and counted. All arthropods were sorted by order or class and by superorder in the case of the Acari. Non-arthropod organisms (e.g. Gasteropoda, Oligochaeta) and larvae were discarded. Arthropod taxa that **had** been found in less than 50% of the total sampling sites (i.e. Orthoptera, Diptera, Dermaptera, Thysanoptera, Lepidoptera, Opiliones, Pseudoscorpionida, Chilopoda, Diplopoda and Isopoda) were also excluded from further analysis to avoid zero inflation. Finally, we retained only 6 out of 16 arthropod orders (Coleoptera, Hymenoptera, Hemiptera, Collembola, Acari and Araneae), which represented the dominant groups. Data from the triplets collected in the same subplot were pooled together and, prior to data analysis, abundance data **was** transformed into **a daily activity density** (D.A.; Brandmayr et al. 2005) following the formula:

$$D.A. = N / ndays * ntraps$$

where N is the abundance of each taxonomic group divided by the sampling effort, expressed as the product **of** the number of days in which traps were active and the number of retrieved traps. This data transformation **has** allowed us to standardize abundance values based on the number of effectively retrieved traps, given that some pitfall traps were lost during the sampling season.

## Data analysis

All statistical analyses were performed with the R 3.5.3 (R Development Core Team, 2019) **software**.

### UHI-effect

In order to investigate, the presence of the UHI-effect, we modelled the response of average daily, diurnal and nocturnal temperatures against urbanization cover, measured as the coverage of impervious surfaces at a small, medium and large scale. Since the levels of urbanization cover (i.e. percentage of **the** urbanization surface) recorded at the three scales **correlated** with each other, we performed three different models for each temperature variable via linear mixed models (LMMs, in accordance with Zuur et al. 2009), assuming a normal distribution for dependent variables. We compared the performance of models fitted with **an** urbanization level in different buffers (%Urb) and selected the model with the lowest AICc value. We preferred the AICc over the AIC because of small dimensions of the datasets (Hurvich and Tsai 1989). In addition, the model with the lowest AICc was kept as a reference point to calculate the AICc differences ( $\Delta AICc$ ) between **the** models, given that models with values of  $\Delta AICc < 2$  are judged to have substantial support and should be considered viable alternatives to the model with the lowest AICc (Burnham and Anderson 2002). In order to further scrutinize whether isolated subplots were characterized with a different microclimate compared to control ones, we also included a categorical variable, distinguishing control and isolated subplots. The models had the following structure:

$$y \sim \%Urb + Isolation + (1|PlotID) + (1|Session)$$

where y indicates average daily, diurnal or nocturnal temperature, %Urb represents the percentage of impervious surface in the buffer (i.e. the level of urbanization) and Isolation represents a categorical variable which distinguishes **the** control and isolated subplots. Given the spatial (two subplots within each plot) and temporal dependence of the data (three sampling sessions), we applied the mixed procedure to include the plot (PlotID) and the sampling session (Session) as **a** random factor to account for the variations they introduced in our samples, rather than **testing** for their direct effects on the dependent variables.

### Response to urbanization

In order to disentangle the relative contribution of urbanization cover, UHI-effect and isolation on the activity density of ground arthropods and to check whether the examined groups responded to the environmental parameters differently, we tested the predictor variables and potential interactions against the activity density of ground arthropods via linear mixed models (LMMs, in accordance with Zuur et al. 2009). We assumed a normal distribution for dependent variables and we used the plot (PlotID) and the sampling session (Session) as random variables. Firstly, we explored the dataset following the standard protocol for data exploration proposed by Zuur et al. (2010). According to Zuur et al. (2009, 2010), the inclusion of outliers and highly correlated predictors in the regression analysis leads to misleading results – type I and II statistical errors. Successively, we used Cleveland's dotplots to assess the presence of outliers in dependent and independent variables, and we investigated multi-collinearity among covariates. The percentages of urbanization measured in different buffers were highly correlated, as well as average, diurnal and nocturnal temperatures (Pearson's  $r > 0.7$ ). On the other hand, temperature and urbanization were not collinear (Pearson's  $r < 0.5$ ) according to the indications provided by Zuur et al. (2009, 2010) and therefore could be retained within the same models. Given that predictor variables were expressed in different measurement units, we standardized them to achieve variance homogenization prior to model fitting, as suggested in Zuur et al. (2009).

The response of arthropod groups to environmental parameters was tested with a two-step approach. First, for each taxonomic group, we proceeded with fitting three separated full models, one for each scale of urbanization cover, and we selected the one with the lowest AICc. This procedure was implemented to check at which scale the response of each group was more evident. We also calculated the  $\Delta AICc$  for all the other models as the difference between the AICc of the considered model and the AICc of the best model, i.e. with the lowest AICc. Models with  $\Delta AICc < 2$  are considered equivalent to the best model (Burnham and Anderson 2002). The full models had the following structure:

$$y \sim \%Urb + \%Urb^2 + Temp + Temp^2 + Isolation + \%Urb*Temp + \%Urb*Isolation + Temp*Isolation + (1|Session) + (1|PlotID)$$

where y refers to the activity density of each arthropod group, %Urb represents the percentage of urbanized surface in the buffer, Temp represents the average daily temperature, and Isolation represents a categorical

variable between the control and isolated subplots. The quadratic terms of predictor variables were included to investigate the occurrence of parabolic responses. Given the spatial and temporal dependence of the data, we applied a mixed procedure to include two grouping variables (PlotID and Session) as random factors, to account for the variation they introduced in our samples, rather than to test for their direct effects on the dependent variables. We adopted a gamma error distribution to keep into account the strictly positive values of activity density data.

Secondly, for each taxonomic group, we performed a backward elimination on the selected model to obtain the minimum adequate model, i.e. the model including only variables that influence the activity density of the examined group.

## RESULTS

### UHI-effect

The level of urbanization (%Urb) ranged from 12.9% to 95.0%, with an average value of 54.8% at a small scale (100 m), from 11.1% to 99.6% with an average value of 56.2% at a medium scale (400 m) and from 18.7% to 94.8% with an average value of 58.8% at a large scale (1,600 m), therefore covering a wide gradient of urbanization. Mean daily temperature values recorded during the sampling period ranged between 19.98°C and 31.85°C, with an average value of 26.14°C. Mean diurnal temperatures ranged from 21.27 °C to 40.58°C, with an average value of 30.12°C, whereas mean nocturnal temperatures ranged between 18.29°C and 26.45°C, with an average value of 22.16°C.

Results of the statistical models showed how both daily and nocturnal temperature values significantly increased with increasing urbanization level in every buffer, whereas diurnal temperature values showed a significant positive relationship only with the urbanization measured in 400 m and 1,600 m buffers (Tab. 1).

In addition, according to the AICc values, the best models for daily and diurnal temperature included urbanization cover at a large scale (1,600 m buffer), whereas the best model for nocturnal temperature included urbanization cover at a small scale (100 m) (Tab. 1 and Fig. 2). These trends were particularly evident in the control subplots, whereas temperature growth was much less pronounced in isolated subplots, even if values were generally higher.

### Scale of response to urbanization

A total of 215 out of 270 pitfall traps were retrieved during the whole sampling season. We collected a total of 99,897 individuals with a mean of 464.3 individuals per pitfall trap (see Fig. 3 for abundances of each group). The best models (i.e. lowest AICc) included urbanization measured in the larger buffer (1,600 m radius) for most groups, except Coleoptera and Acari, whose best models included urbanization at a small (buffer of 100 m of radius) and intermediate (buffer at 400 m of radius) scale, respectively (Tab. 2). However, given that the  $\Delta AICc$  values are  $< 2$ , the response of Coleoptera could be considered equivalent at a large scale, while for Hemiptera the response is equivalent at an intermediate scale.

### Response to environmental parameters

The results of the models show a differential response to urbanization for the different taxonomic groups (Tab. 3 and Fig. 4). The level of urbanization (%Urb) was included in the final models of all groups, except for Coleoptera and Hemiptera, but it proved to have significant positive effect only on Acari. Temperature was included in 4 out of 6 final models, with significant responses for three groups (Tab. 3 and Fig. 5). While Coleoptera and Acari proved to be negatively affected by temperature, Araneae showed a significant positive trend. The quadratic term was included in the final model of Acari with a significant negative effect. Isolation was included in 5 out of 6 groups and we observed significantly higher values of activity density in control subplots than in isolated subplots in 3 out of 5 groups, namely Hymenoptera, Acari and Araneae (Tab. 3 and Fig. 6). The interaction between urbanization level (%Urb) and isolation was included in 4 out of 6 final models, with significant lower values of activity density in isolated subplots compared to the control subplots, with increasing urbanization for Hymenoptera, Acari and Collembola, whereas Araneae showed the opposite trend (Tab. 3 and Fig. 4). The interaction between isolation and temperature was included in the final model of Hemiptera and Acari, but only the former showed a significant effect (Tab. 3 and Fig. 5), with temperature negatively affecting this group in isolated subplots more than in control subplots. The interaction between urbanization levels and temperature was included in the final model of Acari with a significant positive effect, thus underling how temperature positively affects this group in highly urbanized areas (Tab. 3 and Fig. 7).

## DISCUSSION

Urbanization is expected to impact biodiversity and, consequently, ecosystem functioning due to the combined effect of multiple interacting pressures – increasing impervious surfaces, increasing temperature and habitat fragmentation. Thanks to a hierarchical, nested sampling design we were able to evaluate the differential role of impervious surfaces and isolation on the UHI-effect, and tested the combined effect of these pressures on the activity density of six ground arthropod groups.

Our first aim was to check whether the UHI-effect was actually ongoing by relating recorded temperature values with urbanization at a small, medium and large scale, and whether isolation could affect this parameter. We hypothesized that temperature would increase along the urbanization gradient as a consequence of the UHI-effect and our results confirmed our hypothesis. We revealed that temperature values observed during the sampling period significantly increased along the urbanization gradient, confirming the presence of a UHI-effect in the city of Turin, especially at night. Similar trends were observed by Diamond et al. (2014) and Merckx et al. (2018a) in Ohio (USA) and Belgium (Europe) respectively. However, only nocturnal temperature was mainly influenced by urbanization at a local scale — possibly because of the buildings releasing heat stored during the day — while daily and diurnal temperatures better reflect urbanization on a larger scale. As the scale increases, the influence of the adjoining land-uses decreases (Ziter et al. 2019). Thus, we can suppose that night temperatures can be mitigated by the surrounding land cover and the UHI-effect is mainly reflected on a local scale. In addition, nocturnal temperature measured at ground level, like as in this study, seems to be more influenced by microscale site characteristics than air temperature as reviewed by Arnfield et al. (2003). Conversely, during the day, the heat absorbed by impervious surfaces probably creates extremely isolated temperature islands, limiting the possible mitigating effects of surrounding land use. These results point out how urbanization may have climatic repercussions even at a very local scale, exacerbating the UHI-effect and transforming cities into climatic mosaics. This phenomenon has been observed in the city of Baltimore (USA), where the center is 5-10°C warmer than the surrounding area (Brazel et al. 2000; George et al. 2007). In addition, our results demonstrated that isolated patches, such as roundabouts, have significantly higher temperature values compared to control ones and their temperature values appear to be less influenced by urbanization compared

1 to the control sites. This is in accordance with the literature, since altered physical and chemical conditions,  
2 such as microclimate alteration, have been documented in ruderal habitats, like road edges, as a result of road  
3 operation and traffic (Parris and Schneider 2008), further contributing to the creation of a climatic mosaic in  
4 cities. Moreover, control patches can be influenced by surrounding land use, e.g. tree canopy cover of  
5 adjacent forested areas may mitigate the UHI-effect (Ziter et al. 2019), while this is not possible in isolated  
6 patches.  
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14 Our second aim was to examine to what scale urbanization could affect ground arthropods, by considering  
15 the percentage of impervious surfaces at a small, medium and large scale. We showed that responses of  
16 ground arthropods were better explained by large scale urbanization, contradicting our hypothesis. These  
17 outcomes apparently contradict literature, since several works highlight how local factors usually have a  
18 stronger effect than landscape factors (Angold et al. 2006; Small et al. 2006; Schwartz et al. 2013; Bennett  
19 and Lovell 2014; Do et al. 2014; Philpott et al. 2014; Otoshi et al. 2015; Kyrö et al. 2018), even if Delgado  
20 de la Flor et al. (2017) and McCary et al. (2018) observed how covariation between local and landscape  
21 factors affect ground-active arthropods. In particular, McCary et al. (2018) highlighted how the shared  
22 variance between local, i.e. habitat type, landscape and landscape fragmentation variables explained half of  
23 the variation in several ground-active arthropods, whereas Delgado de la Flor (2017) evidenced a combined  
24 effect of local habitat type and buildings in the landscape on ground beetle community composition.  
25 However, as habitat types differed profoundly in these studies, it remained less clear to what extent the  
26 measured response was a consequence of habitat type or urbanization *per se*. Since we consistently sampled  
27 the same habitat type along the urbanization gradient, we were able to disentangle the scale of response  
28 without confounding factors, underpinning how urbanization affects ground arthropods at a large scale. The  
29 only exception is represented by Acari, which demonstrated a medium scale response, whereas, according to  
30 the minimum adequate model, Coleoptera were not affected by urbanization.  
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53 Our third aim was to evaluate the differential effect of urbanization, the UHI-effect and isolation on the  
54 activity density of different taxonomic groups and whether the examined groups showed different responses  
55 to these environmental parameters. We hypothesized arthropod groups would be differentially affected by  
56 urbanization, temperature and isolation, showing idiosyncratic responses, and our results confirmed our  
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hypothesis. In respect to this, our sampling design was particularly suitable in disentangling the effect of patch isolation and urbanization on the different taxonomic groups here investigated.

Our results showed that Acari and Araneae were mostly affected by urbanization, as their final models included all the three examined environmental parameters, namely urbanization cover, temperature and patch isolation. These results are in accordance with the review provided by El-Sabawii (2018), who highlighted how predator groups, such as Acari and Araneae, are more affected **by urbanization than others**. A weaker response was observed for Hymenoptera, here mainly represented by ants, Collembola and Hemiptera, mainly represented by aphids, whose final models included two parameters. In particular, patch isolation showed a **significantly** negative effect for all groups, suggesting how their fitness in urban environments may be negatively affected by their low dispersal. Coleoptera showed the weakest response, as they were **only affected** by one parameter, namely temperature. This result may be due to the heterogeneous composition of Coleoptera in terms of feeding guilds, with the response of each guild being masked **by** the others.

By using the percentage of impervious surfaces as a proxy of urbanization, we **have** highlighted how this parameter alone does not affect examined taxonomic groups, except for Acari that showed a significant positive trend with increasing urbanization. However, if we consider the interaction between urbanization cover and patch isolation, we could highlight extremely variable responses among taxonomic groups: in particular, Collembola and Hymenoptera showed a positive and negative trend in control and isolated patches respectively with increasing urbanization, whereas Araneae showed the opposite trend. Although species richness positively responds to increasing availability of natural habitats even in anthropogenic environments (e.g. Piano et al. 2017b), contradictory results are common when analysing individual densities. For instance, Kotze et al. (2011) highlighted how in certain cities the abundance of beetles decreased with increasing urbanization, while in others this pattern was less consistent, or even opposite, in the case of communities dominated by introduced species (Niemelä and Kotze 2009). Such inconsistent responses reflect the complex nature of urban habitats and urban arthropod communities. On **the** one hand, pollution - as well as the high level of impermanence in urban habitats - may lead to an increased stochasticity in environmental conditions (Parris 2016), which may negatively affect particular groups. For instance, predators, like spiders, are expected to be sensitive to pollution because they feed at higher trophic



levels, where toxins and pollutants tend to accumulate (see El-Sabawii 2018 for a review on this topic). On the other hand, urban patches provide a high availability of trophic resources (Parris 2016), which might favour generalist and alien species. For instance, pest arthropods, like some mites, are expected to increase in urban areas, due to human activity that eradicate native predators (Shocat et al. 2010). Similarly, omnivores, such as ants, which here represent 95% of Hymenoperans, are probably favoured in urban areas by the increase of anthropogenic food resources (El-Sabawii 2018). These changes at different trophic levels may have repercussions on the entire trophic food web, compromising the ecosystem services provided by the ground arthropod fauna, such as litter decomposition or pest control. Model outcomes displayed opposite trends of arthropod groups against temperature, which show a negative effect on Coleoptera and Acari and a positive effect on Araneae; whereas Hemiptera are favoured by temperature in control patches and disfavoured in isolated ones. Overall, the response to temperature increase has been shown to be extremely variable across arthropod groups as a consequence of variable physiological heat tolerance in ectotherms (Youngsteadt et al. 2017). Increasing temperature may, in fact, favour the fitness of those organisms with a wide thermal tolerance breadth, whereas species with a narrow thermal tolerance breath will be negatively affected (Sunday et al. 2012). This is especially true at mid-latitudes, as demonstrated by physiological tests, which showed that the lowest thermal tolerance to the UHI effect is observed between 30° and 35°N or S (Chown and Duffy 2015), whereas response patterns within the temperate zone showed contradictory results (Pelini et al. 2014). On the basis of measured physiological tolerances, two recent studies have predicted that mid-latitudes (between 20° and 40°) will encompass strong variability among taxa regarding the effects of urban warming and climate change on their fitness (Kingsolver et al. 2013; Chown and Duffy 2015). Moreover, the response of arthropod groups to environmental temperature may also be mediated by other environmental parameters, as demonstrated by the final model of Acari, which included the interaction between the urbanization cover and temperature. In respect to this group, higher temperatures have a negative effect on activity density, but this effect decreases and disappears with increasing urbanization cover, suggesting how the effect of urbanization *sensu stricto* may override the UHI-effect. In addition, the response to the UHI-effect may be even more complex since it seems to be mediated by life-history traits, such as dispersal capacity (Merckx et al. 2018a). Our results confirm such a response to temperature

1 increase, pointing out how the repercussions of the UHI effect are extremely hard to predict and therefore  
2 mitigate.  
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5 It should be noted that temperature data recorded in the field with dataloggers is highly influenced by shield  
6 methods and ad-hoc, custom-fabricated shields, such as those used in this work, and may produce bias in  
7 temperature measures, especially in urban areas (Terando et al. 2017). Therefore, these results should be  
8 interpreted with caution.  
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14 Finally, we observed a consistent negative effect of isolation on 5 out of 6 taxonomic groups with significant  
15 results for Hymenoptera, Acari and Araneae. Moreover, we proved that this effect is even stronger at  
16 increasing levels of urbanization. Despite always showing higher values in control vs isolated patches,  
17 spiders represent an exception to this pattern since their abundance in isolated patches increases with the  
18 rising level of urbanization. This result contradicts literature, since Braaker et al. (2014) demonstrated how  
19 isolated surrogates of natural habitats in urban areas, such as green roofs, might sustain populations of highly  
20 dispersive arthropods, e.g. bees and weevils, but limit poor dispersers, e.g. carabids and spiders. However, in  
21 some cases (e.g. small Linyphiids or young instars of Lycosids) spiders may show high dispersal capacity via  
22 ballooning, therefore overcoming the limits imposed by isolation. Therefore, according to our results,  
23 isolated patches in urban areas might be considered as islands surrounded by an inhospitable matrix that  
24 limits the dispersion of organisms. While habitat connectivity between isolated patches does not represent a  
25 limit for highly dispersive groups, it might severely limit poor dispersers, with serious repercussions on  
26 biodiversity.  
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45 Our results emphasize how a multitaxonomic approach may help in unravelling apparently contradictory  
46 patterns in urban areas. Indeed, we isolated the response of taxonomic groups on an urbanization level, UHI-  
47 effect and patch isolation, which may act in opposite directions depending on the sensitivity of each group.  
48  
49 In addition, we highlighted how ground arthropod responses mainly occur on a large scale. In conclusion,  
50 urbanization has negative ecological repercussions by diversely affecting the abundance of several  
51 taxonomic groups of ground arthropods, which play a central role in a variety of processes, or represent a  
52 food source for higher trophic levels, thus suggesting potential negative effects on ecosystem functionality  
53 and services.  
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## Tables

**Table 1** AICc and  $\Delta$ AICc values for models performed with urbanization at small, medium and large scale and estimated parameters and p-values (in brackets) for models performed on temperature variables against urbanization (%Urb) and patch isolation (Isolation) in each buffer. The best models and significant results are reported in bold.

	DAILY TEMPERATURE (°C)			DIURNAL TEMPERATURE (°C)			NOCTURNAL TEMPERATURE (°C)		
	100 m	400 m	1600 m	100 m	400 m	1600 m	100 m	400 m	1600 m
<b>AICc</b>	343.3	341.6	<b>338.0</b>	424.9	423.1	<b>419.9</b>	<b>241.9</b>	246.0	245.7
<b><math>\Delta</math>AICc</b>	5.3	3.6	<b>0</b>	5	3.2	<b>0</b>	<b>0</b>	4.1	3.8
<b>%Urb</b>	<b><math>0.024 \pm 0.009</math></b>	<b><math>0.025 \pm 0.008</math></b>	<b><math>0.036 \pm 0.010</math></b>	$0.027 \pm 0.016$	<b><math>0.033 \pm 0.015</math></b>	<b><math>0.051 \pm 0.018</math></b>	<b><math>0.02 \pm 0.004</math></b>	<b><math>0.017 \pm 0.004</math></b>	<b><math>0.021 \pm 0.005</math></b>
	(0.009)	(0.003)	(<0.001)	(0.085)	(0.027)	(0.006)	(<0.001)	(<0.001)	(<0.001)
<b>Isolation</b>	<b><math>1.29 \pm 0.478</math></b>	<b><math>1.35 \pm 0.471</math></b>	<b><math>1.4 \pm 0.460</math></b>	<b><math>2.41 \pm 0.854</math></b>	<b><math>2.5 \pm 0.842</math></b>	<b><math>2.58 \pm 0.826</math></b>	$0.133 \pm 0.231$	$0.198 \pm 0.238$	$0.227 \pm 0.238$
	(0.010)	(0.005)	(0.003)	(0.006)	(0.004)	(0.003)	(0.565)	(0.407)	(0.344)

**Table 2** AICc and  $\Delta$ AICc values for models performed with urbanization at small, medium and large scale. The best models, namely those with the lowest value of AICc, are reported in bold.  $\Delta$ AICcs are calculated as the difference between the AICc of the examined model and the AICc of the best model. Models with  $\Delta$ AICc < 2 could be considered as equivalent of the best model.

		100 m	400 m	1600 m
Coleoptera	AICc	<b>558.5</b>	561.2	560.0
	$\Delta$ AICc	<b>0</b>	2.7	1.5
Hymenoptera	AICc	579.9	578.0	<b>575.4</b>
	$\Delta$ AICc	4.5	2.6	<b>0</b>
Hemiptera	AICc	448.0	446.8	<b>445.5</b>
	$\Delta$ AICc	2.5	1.3	<b>0</b>
Collembola	AICc	602.6	601.9	<b>596.8</b>
	$\Delta$ AICc	5.8	5.1	<b>0</b>
Acari	AICc	570.1	<b>563.8</b>	567.6
	$\Delta$ AICc	6.3	<b>0</b>	3.8
Araneae	AICc	424.7	424.2	<b>419.3</b>
	$\Delta$ AICc	5.4	4.9	<b>0</b>

**Table 3** Estimated parameters  $\pm$  standard errors and p-values (in brackets) of final models selected for each taxonomic group. Significant results are reported in bold.

Taxon	Scale of response	%Urb	%Urb <sup>2</sup>	Temp	Temp <sup>2</sup>	Isolation	%Urb: Isolation	Temp: Isolation	%Urb: Temp
Coleoptera	Small	-	-	<b>-0.434 <math>\pm</math> 0.121</b> ( <b>&lt;0.001</b> )	-	-	-	-	-
Hymenoptera	Large	0.206 $\pm$ 0.180 (0.252)	-	-	-	<b>-0.472 <math>\pm</math> 0.098</b> ( <b>&lt;0.001</b> )	<b>-0.208 <math>\pm</math> 0.104</b> ( <b>0.045</b> )	-	-
Hemiptera	Large	-	-	0.089 $\pm$ 0.184 (0.629)	-	-0.352 $\pm$ 0.184 (0.056)	-	<b>-0.408 <math>\pm</math> 0.187</b> ( <b>0.029</b> )	-
Collembola	Large	0.251 (0.252)	-	-	-	-0.137 (0.436)	<b>-0.563</b> ( <b>0.002</b> )	-	-
Acari	Medium	<b>0.920 <math>\pm</math> 0.275</b> ( <b>&lt;0.001</b> )	-	<b>-0.581 <math>\pm</math> 0.168</b> ( <b>&lt;0.001</b> )	<b>-0.148 <math>\pm</math> 0.093</b> ( <b>0.003</b> )	<b>-0.466 <math>\pm</math> 0.207</b> ( <b>0.025</b> )	<b>-0.546 <math>\pm</math> 0.210</b> ( <b>0.009</b> )	0.417 $\pm$ 0.239 (0.082)	<b>0.401 <math>\pm</math> 0.137</b> ( <b>0.003</b> )
Araneae	Large	-0.014 $\pm$ 0.008 (0.102)	-	<b>0.103 <math>\pm</math> 0.046</b> ( <b>0.026</b> )	-	<b>-1.06 <math>\pm</math> 0.422</b> ( <b>0.012</b> )	<b>0.015 <math>\pm</math> 0.006</b> ( <b>0.020</b> )	-	-

## Figure captions

**Fig. 1** Map of the sampling plots with buffers (black circles) and impervious areas evidenced (dark grey).

**Fig. 2** Predicted values and confidence intervals for daily, diurnal and nocturnal temperatures modelled against urbanization cover (%Urbanization) in both control (solid line) and isolated (dashed line) sites. Predicted values modelled against %Urbanization were calculated using the buffer included in the selected model for each temperature measure.

**Fig. 3** Total abundance of ground arthropods sampled during the study.

**Fig. 4** Predicted values and confidence intervals for activity density of the different groups modelled against urbanization cover (%Urbanization) in both control (solid line) and isolated (dashed line) subplots, with observed values (green dots = control subplots; grey dots = control subplots). Predicted values modelled against %Urbanization were calculated using the buffer included in the selected model for each taxonomic group.

**Fig. 5** Predicted values and confidence intervals for activity density of Coleoptera, Acari and Araneae modelled against daily temperature in both control (solid line) and isolated (dashed line) subplots, with observed values (green dots = control subplots; grey dots = control subplots).

**Fig. 6** Boxplots representing observed activity density values for each taxonomic group in control and isolated sites. Asterisks indicate significant differences according to statistical models (significance level: \*0.05, \*\*0.01, \*\*\*0.001).

**Fig. 7** Predicted values and confidence intervals for activity density of Acari and the interaction between urbanization and temperature. Lines represent the temperature effect at low (0%, continuous line), intermediate (50%, dashed line) or high (100%, dotted line) urbanization cover.

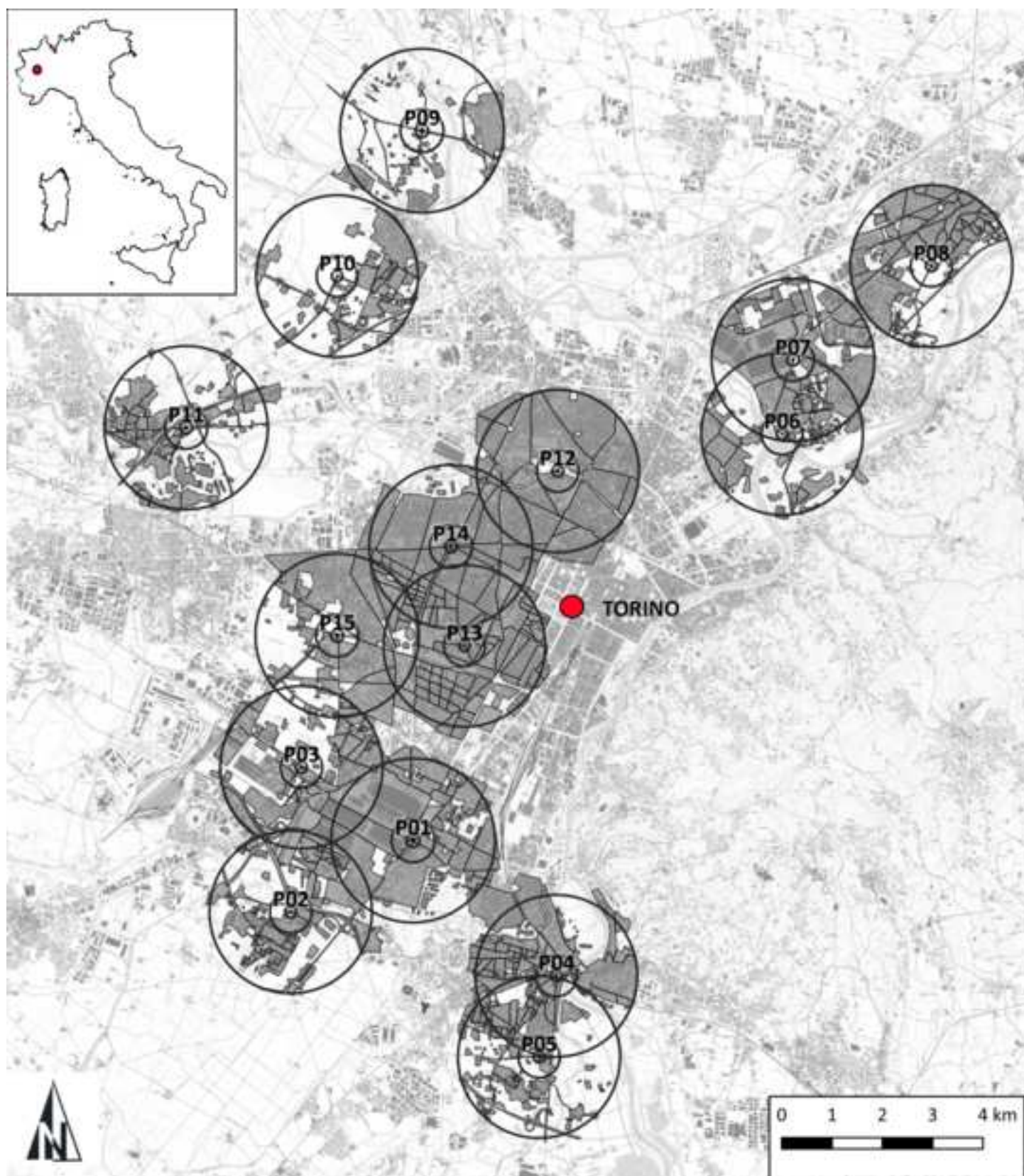


Figure 2

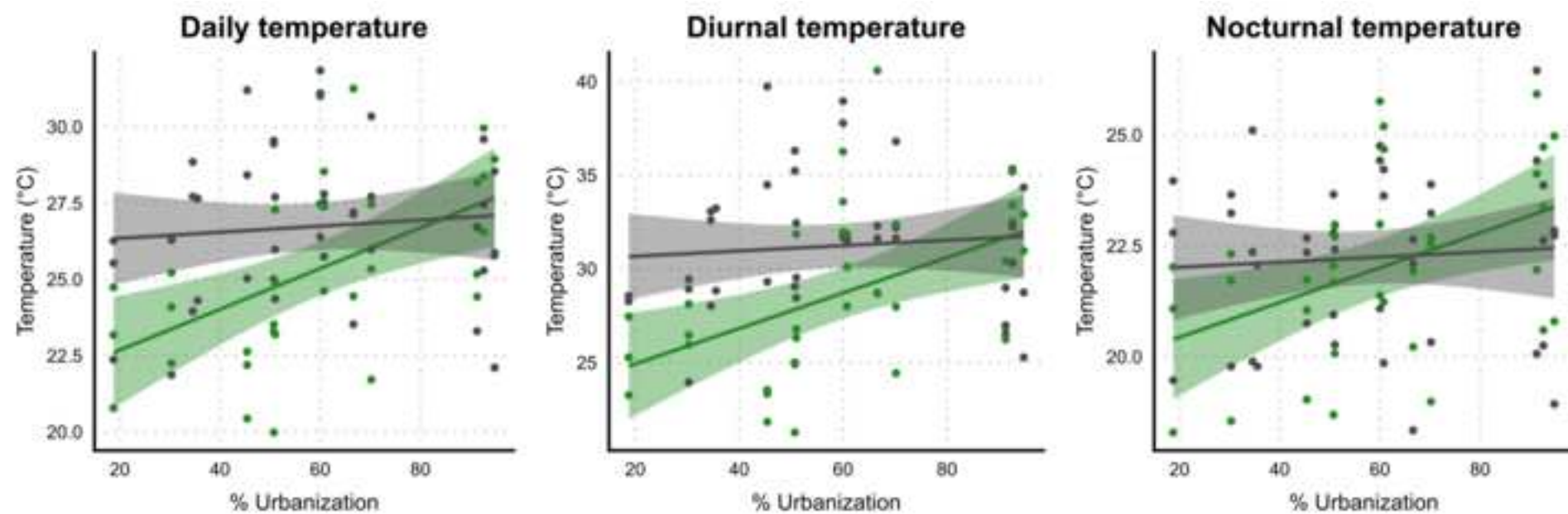




Figure 3

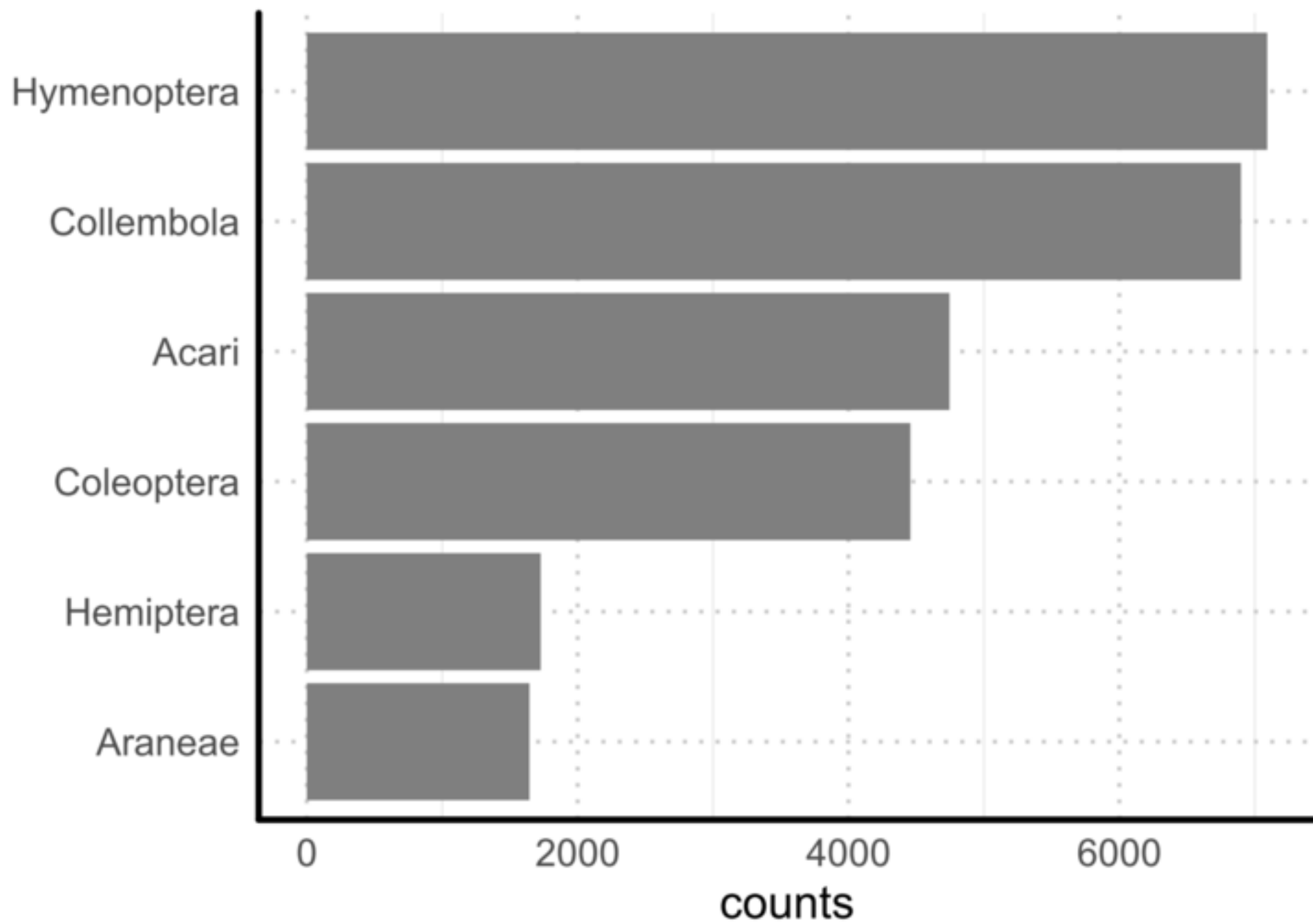


Figure 4

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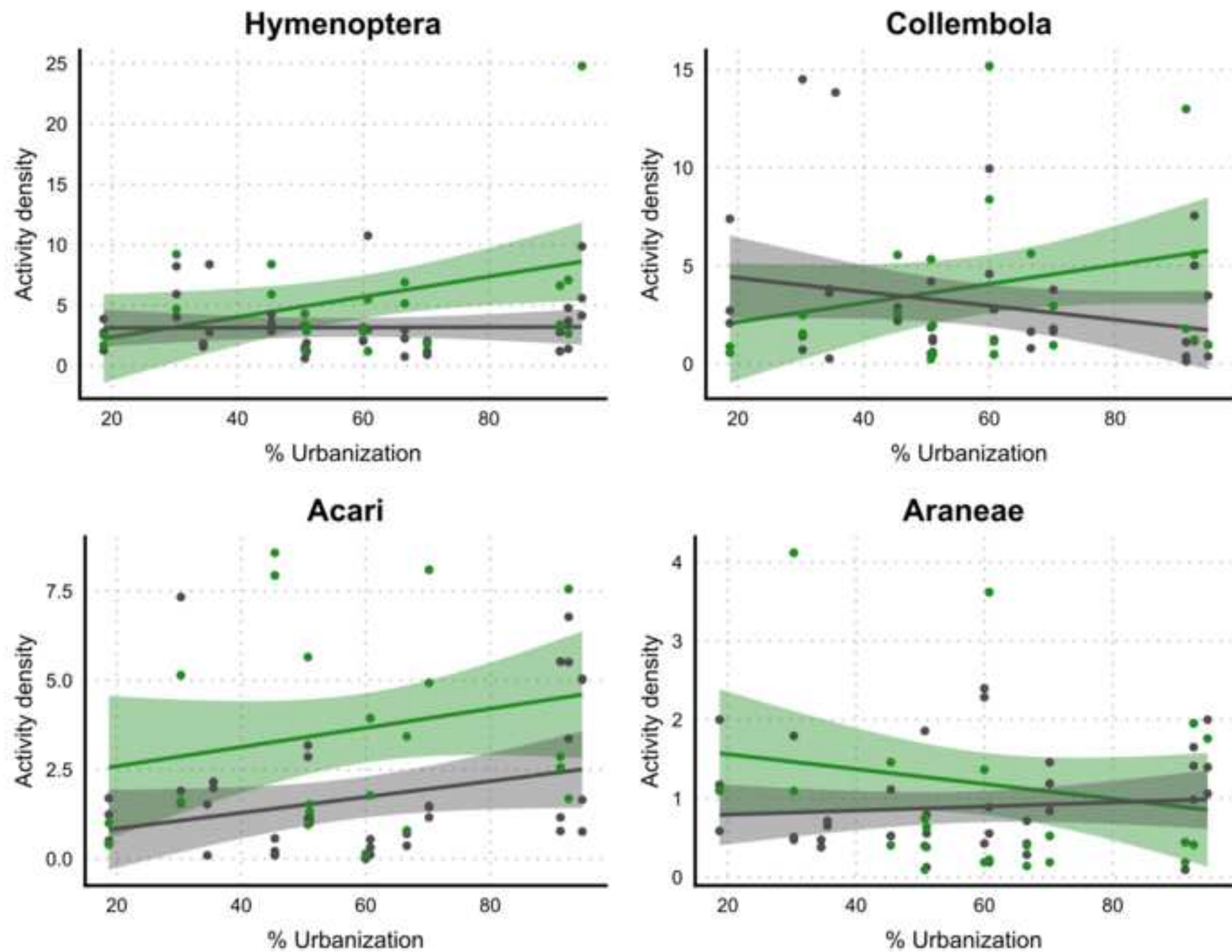


Figure 5

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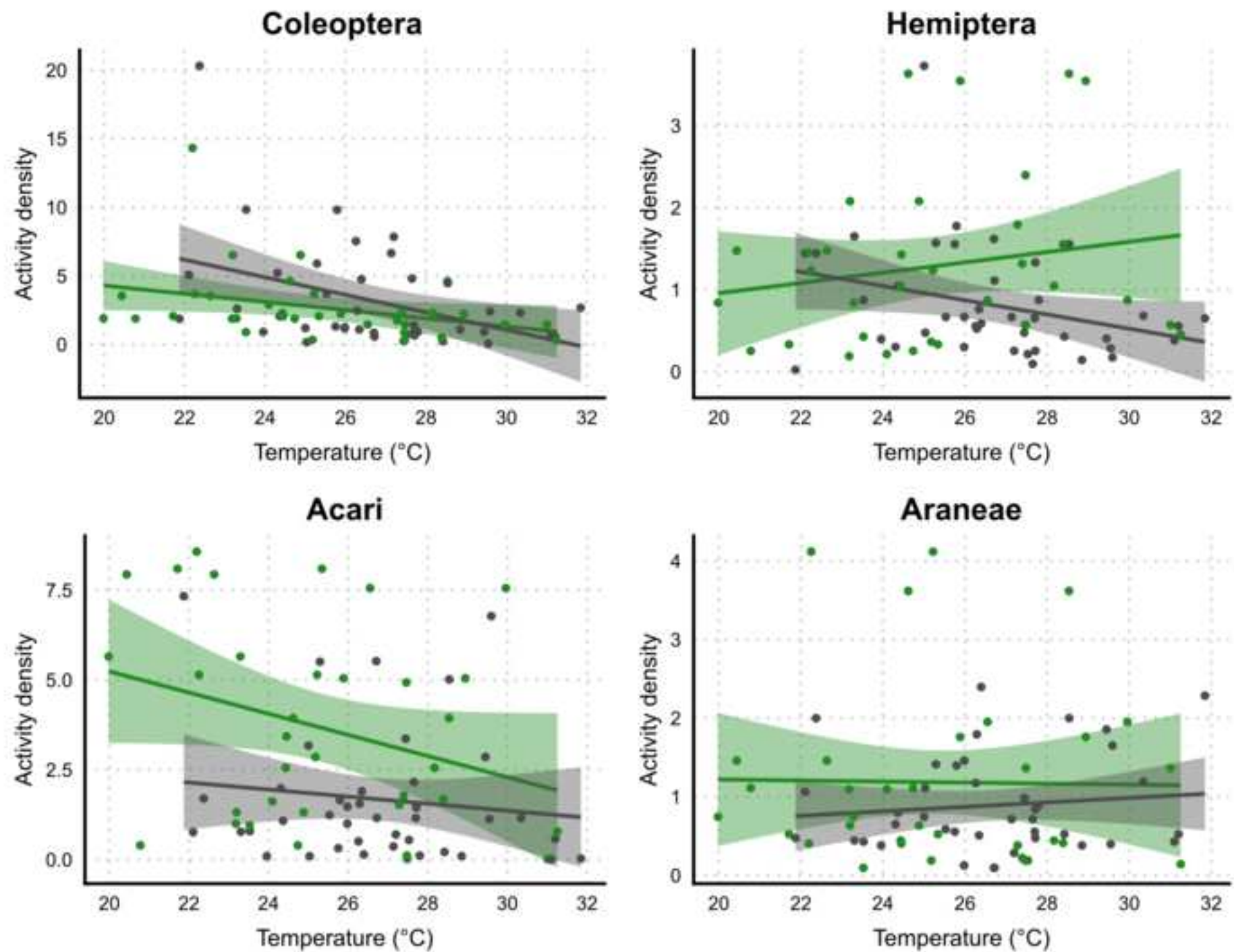


Figure 6

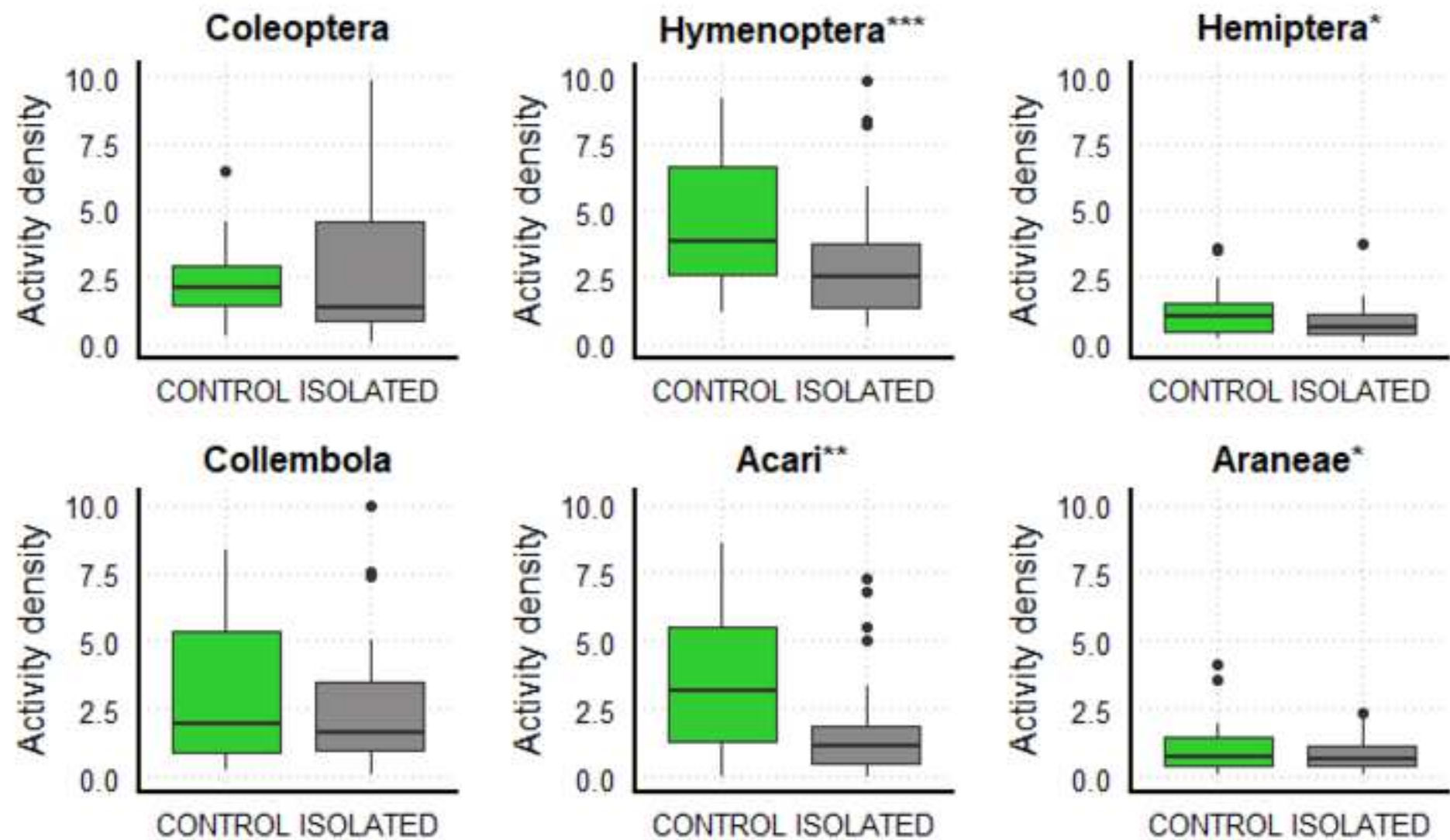
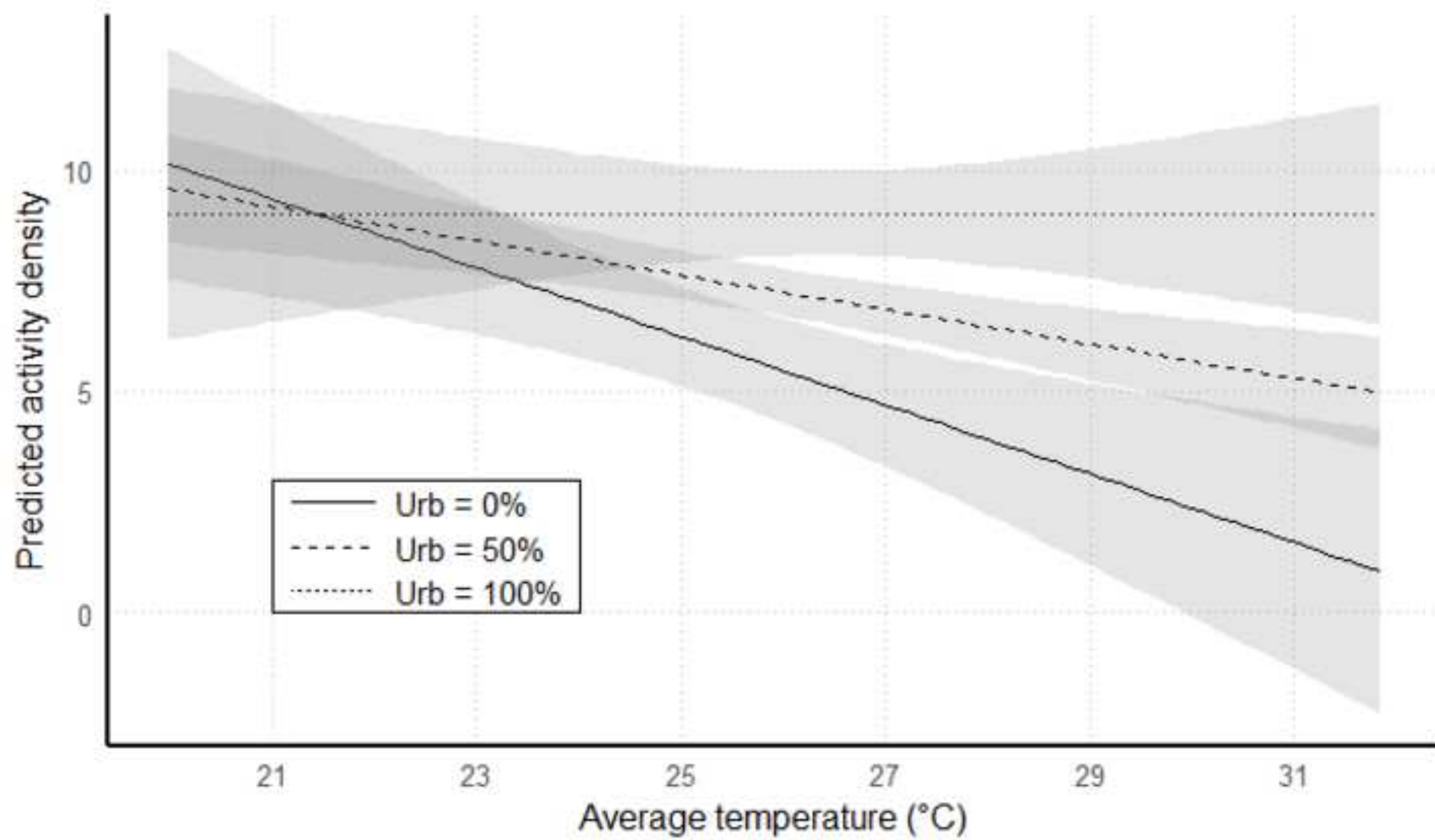


Figure 7



COMMENTS FOR THE AUTHOR:

Co-Editor-In-Chief: I agree with the recommendation of the Associate Editor and suggest you find a native English speaker who can help improve the readability of your manuscript. Upon receipt of a corrected manuscript, we will be able to accept your manuscript.

Dear Dr. Isaia,

Thank you for your resubmission and attention to addressing the comments of the reviewers. I think the manuscript is acceptable pending an additional read from a native English speaker.

All the best,  
Susannah Lerman, PhD  
Associate Editor  
USDA Forest Service

>>> Dear Editors,

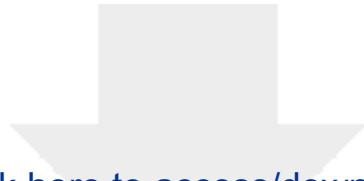
Many thanks for the positive comments on our manuscript. We adjusted the text following the suggestions provided by a native speaker as you required. We hope that this could substantially improve the readability of our manuscript.

Sincerely yours,

Marco Isaia

Francesca Bona

Elena Piano



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**Supplementary Material**

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